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WHITE PAPER

The ultimate microscopy—enabling nanotechnology

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The birth of nanoscience and nanotechnology is generally attributed to a keynote talk by physicist Richard Feynman in a 1959 American Physical Society meeting at the California Institute of Technology.* In this talk, Feynman proposed a level of miniaturization and microscopy that sounded outlandish at the time, but has, in fact, become reality. It is not surprising to find that these predictions were made just four years after the field ion microscope (FIM) was first used to image individual atoms of a metal surface. Atom probe tomography (APT), as the technological successor to FIM, is the ultimate in atomic analysis, providing the highest three-dimensional (3D) spatial resolution available. If you can see it, you can understand it, and atom probe microscopes precisely see the locations and identity of individual atoms in a 3D volume.

Atom probe tomography

Samples for APT analysis are shaped into nano-needles (apex diameter of ~100 nm) and held at cryogenic temperatures to freeze out thermal motion of surface atoms. A voltage is applied to the highly curved apex creating an amplified electric field that ionizes and removes ("field evaporates") atoms at atomic-plane edges in an orderly fashion. By pulsing the electric field or pulsing the sample temperature with a laser, time-of-flight mass spectrometry can be performed on the departing ions. Using a position-sensitive detector, the departing ion impacts are detected and projected back to their original location in the specimen. In this way, a ~100 nm surface is projected onto a ~100 mm detector, providing ~10^6 magnification. This high magnification provides better than 10^{-9} m (nanoscale) spatial resolution and ion identity (mass) resolved with better than 1 part in 1200 resolution.

A working atom probe microscope was first completed in 1967. The technique was slowly developed thereafter and used to study materials at the nanoscale. During the 1990s and early 2000s, commercial development of the technique was enabled by developments in high-speed solid-state electronics, laser technology, computing capability, focused ion-beam availability, and silicon fabrication techniques. Adoption of the technique was further driven by the demand for a characterization technique that could meet the needs of new nanoscale materials being developed. The first local electrode atom probe (LEAP) was sold in 2003, and there are now more than 110 in use worldwide.

Current uses of and breakthroughs attributable to APT

Applications for APT have expanded rapidly during the past decade. Previously, APT analysis relied almost exclusively upon voltage pulsing, so virtually all of the work from the 1970s through 2000 involved metals analysis. With the addition of laser-pulsing capability and standard methods for correlative analysis (SEM, TEM/STEM, EDS, TKD, SIMS, etc.), more sophisticated applications have been pursued and reported in the literature and include (without being comprehensive):

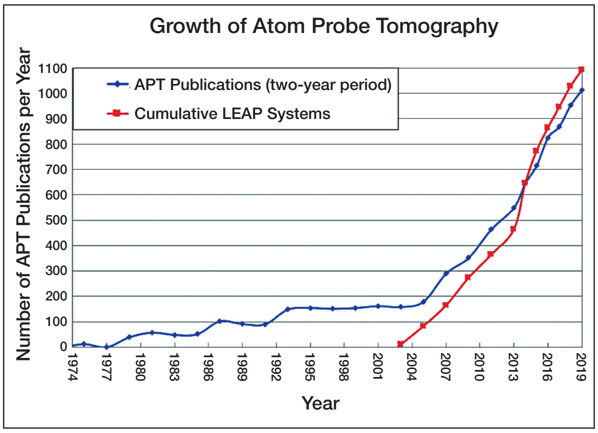
- Development of new and improved high-temperature superalloy metals (e.g., jet engines)
- 3D visualization of dopants in nanoscale transistors used in cutting-edge microprocessors
- Study of hydrogen affecting materials
- Development of improved GaN-based light-emitting diodes that have reduced worldwide electrical usage
- Study of failure mechanisms in structural materials in power plants
- Verification of aspects of radioisotope dating applications in geological materials.

Improved features and technology in the latest LEAP microscopes have been key in expanding applications, and newer features that enable optimization of sample preparation and extend the ability to do correlative work with vacuum and cryogenic transfer systems promise to impact new development. This transport capability is an enabling technology for developing hydrogen and biological applications that require carefully controlled environments and temperatures.

CAMECA is the world leader of APT instrumentation. Our LEAP and EIKOS atom probes are used around the world to drive studies of materials at the atomic scale. As a leading-edge technology, APT is of special importance to companies and research institutions looking to broaden and advance their research and products. Nearly all leading semiconductor manufacturers already use APT in the R&D laboratory and/or near the fab; meanwhile, the use of APT has quadrupled in academic institutions during the past 10 years.

The use of APT has expanded by nearly an order of magnitude during the last decade, and as new applications continue to be developed, there is no reason to expect the trend to stop.

*R. Feynman, *Eng. Sci.* **23**, 22 (1960).
See all references at www.atomprobe.com keyaptlinks/MRS_APT_Whitepaper.



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